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INVESTIGATION OF TEST METHODS,
MATERIAL PROPERTIES, AND PROCESSES
FOR SOLAR CELL ENCAPSULANTS

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4800 Oak Grove Drive
Pasadena, California 91103



ENCAPSULATION TASK OF THE LOW-COST
SILICON SOLAR ARRAY PROJECT

The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

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By

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Table of Contents

	<u>Page</u>
I. Summary.	1
II. Introduction	3
III. Advanced Cure Systems.	7
Chemistry	7
Ethylene/Vinyl Acetate.	11
Ethylene/Methyl Acrylate.	18
IV. Soiling Experiments.	24
V. Accelerated Aging Experiments.	31

Appendix

List of Tables:

1A	Soiling Experiments; Change in I_{sc} , Sunadex.	A-1
1B	Soiling Experiments; % Change in I_{sc} , Sunadex.	A-2
2A	Soiling experiments; Change in I_{sc} , Acrylar.	A-3
2B	Soiling Experiments; % Change in I_{sc} , Acrylar.	A-4
3A	Soiling Experiments; Change in I_{sc} , Tedlar	A-5
3B	Soiling Experiments; % Change in I_{sc} , Tedlar	A-6
4	Soiling Experiments; Rainfall During Exposure Period	A-7
5	Polymer Aging Studies; EVA, A8901C, RS/4	A-8
6	Polymer Aging Studies; EVA, A9918, RS/4.	A-9
7	Polymer Aging Studies; EMA 13439, RS/4	A-10
8	Polymer Aging Studies, Polyurethane Z-2591, RS/4	A-11
9	Polymer Aging Studies; Butyl Acrylate 13870, RS/4.	A-12
10	Polymer Aging Studies; Tedlar 100 BG30UT, RS/4	A-13
11	Polymer Aging Studies; Tedlar 4462, RS/4	A-14
12	Polymer Aging Studies; Acrylar X-22417, RS/4	A-15
13	Polymer Aging Studies; Fluorex-A, RS/4	A-16
14	Polymer Aging Studies; Scotchpak 20CP, RS/4.	A-17
15	Polymer Aging Studies; Tedlar 100BS30WH, RS/4.	A-18
16	Polymer Aging Studies; Korad 63000, RS/4	A-19

Table of Contents
(continued)

Page

List of Figures:

1	Half-Life Graph, New Candidate Peroxides.	A-20
2	Soiling Experiments, Sunadex Glass.	A-21
3	Soiling Experiments, Acrylar Film	A-22
4	Soiling Experiments, Tedlar Film.	A-23

I. SUMMARY

Springborn Laboratories, Inc. is engaged in a study of evaluating potentially useful low cost encapsulation materials for the Flat-Plate Solar Array project (FSA) funded by the Department of Energy and administered by the Jet Propulsion Laboratory. The goal of the program is to identify, evaluate, test and recommend encapsulant materials and processes for the production of cost-effective, long life solar cell modules.

During the past quarter technical investigations concerned the development of advanced cure chemistries for lamination type pottants; the continued evaluation of soil resistant surface treatments, and the results of an accelerated aging test program for the comparison of material stabilities.

New compounds were evaluated for efficiency in curing both ethylene/vinyl acetate and ethylene/methyl acrylate pottants intended for vacuum bag lamination of solar cells. One compound in particular, designated Lupersol - TBEC (Lucidol Division of Pennwalt Corp.) was found to be unusually effective in promoting the rapid cure of both these materials. Formulation of these resins with TBEC resulted in compositions of very high gel content, lower temperatures of activation, and much lower cure times, even in the ethylene/methyl acrylate polymer that is more difficult to cure. It is expected that TBEC modified pottant formulations may permit the lamination/encapsulation step to be operated at lower temperatures, higher speed, higher throughput and a much wider tolerance for intentional or accidental variations in the cure schedule. Investigations of this new curing agent will be emphasized in future work.

An experimental program continued to determine the effectiveness of soil resistant coatings. These coatings are intended to be surface treatments applied to the sunlight side of solar modules and function to prevent the persistent adhesion of soil to the surface, aid in its removal, and consequently keep the power output high. These treatments have been applied to "Sunadex" glass, Tedlar and oriented acrylic film. The treatments are based on silicone, acrylic, and fluorosilane chemistries. After one year of outdoor exposure, the most effective treatment for Sunadex glass appears to be a fluorosilane designated L-1668, and for both the organic films a silane modified adduct of perfluoric acid gave the best results. These treatments gave improvements of 2.5 to 4% in power transmission measured with a standard cell. The surface treatments were found to be

"self cleaning" and power transmissions varied with the degree of rainfall. After one year of time there is evidence that the treatments are slowly being lost and consequently a maintenance schedule may be required to maintain effectiveness over long periods of time.

An accelerated aging test program is underway at Springborn Laboratories for the dual purpose of generating practical and empirical data relating to the service life of candidate encapsulation materials, and to provide data that may be useful in a predictive type of analysis. Seven exposure conditions are being used: (a) outdoor aging, (b) air oven thermal aging, (c) outdoor photothermal aging, (d) controlled environment reactors, (e) RS/4 sunlamp, (f) RS/4 sunlamp plus water spray, and (g) RS/4 sunlamp at 85°C and 85% relative humidity. Of these conditions, the results of RS/4 (50°C) only, are presented due to the current lack of data from the other conditions.

The data reveals that the EVA formulations are performing extremely well and have survived 30,000 hours exposure to date with no significant change in properties. In comparison, the uncompounded resin begins to degrade in about 500 hours. The other potting materials are also surviving without change, however they have not yet accumulated the same number of hours. The fully compounded commercial grade of EMA has endured 7,600 hours, and the casting syrups, polyurethane (Z-2591) and butyl acrylate (BA 1387), have been exposed for 6,000 and 7,600 hours, respectively with no apparent degradation.

Other candidate encapsulants include back cover and outer cover films. None of the back cover films show any signs of degradation after 8,000 hours exposure and the transparent Tedlar 100BG30UT is unaffected after over 15,000 hours. The Acrylar biaxially oriented acrylic film, does show considerable change in properties. After 2,000 hours the tensile strength appears to decrease to 40% of control value, but is then stable up to 12,000 hours of exposure. Stress relaxation of the film was speculated to be the cause of this effect, however the molecular weight was also found to decrease gradually over the exposure period. Despite measurable changes, this film may still prove to be a viable outer cover material.

II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.70 per peak watt ($\$70/\text{m}^2$) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirement, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per m^2 in midday sunlight, the capital cost of the modules may be calculated to be \$70.00 per m^2 . Out of this cost goal, only 20 percent is available for encapsulation due to the high cost of the cells, interconnects, and other related components. The encapsulation cost allocation^a may then be stated as \$14.00 per m^2 which included all coatings, pollutants, and mechanical supports for the solar cells.

a. JPL Document 5101-68

The former cost allocation for encapsulation materials, was $\$2.50/\text{m}^2$ ($0.25/\text{ft}^2$) in 1975 dollars, or $\$3.50/\text{m}^2$ ($\$0.35/\text{ft}^2$) in 1980 dollars. The current cost allocation of $\$14/\text{m}^2$ is an aggregate allocation for all encapsulation materials including an edge seal and gasket.

Assuming the flat plate collector to be the most efficient design, photovoltaic modules are composed of seven basic construction elements. These elements are (a) outer covers; (b) structural and transparent superstrate materials; (c) pottants; (d) substrates; (e) back covers; (f) edge seals and gasket compounds; and, (g) primers. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Throughout this program, extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

<u>Construction Elements</u>	<u>Approximate Cost Allocation^(a) (\$/m²)</u>
● Substrate/Superstrate (Load Bearing Component)	7.00
● Pottant	1.75
● Primer	0.50
● Outer Cover	1.50
● Back Cover	1.50
● Edge Seal & Gasket	1.85

(a) Allocation for combination of construction elements: \$14/m².

From the previous work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The following chart shows the materials of current interest and their anticipated functions.

Status of Candidate Encapsulation Materials
(Identified in Springborn Labs Program)

- | | |
|--|---|
| 1. Surface materials & modification | Under development (Springborn) |
| 2. Top Covers | |
| (with UV screening property) | |
| a. Glass | Available |
| b. Tedlar X00 BG 30 UT | Available (DuPont) |
| c. Acrylar Acrylic film
(X-2241-6, -7) | Available (3M Corp.) |
| 3. Pottants | |
| a. Ethylene Vinyl Acetate
(A9918) | Available (Springborn) |
| b. Ethylene Methyl Acrylate
(13439) | Available (Springborn) |
| c. Aliphatic Polyether Urethane
(Z-2591) | Available (Development Associates) |
| d. Poly Butyl Acrylate
(13870) | Available (Springborn) |
| 4. Electrical and mechanical spacer | |
| a. Non-woven glass mats | Available (Crane Co.) |
| 5. Substrate panels | |
| a. Hardboards | Available (Masonite, "Super-Dorlux",
Laurel 200, Ukiah Standard Hardboard) |
| b. Strandboard | Under development (Potlatch Corp.) |
| c. Glass-reinforced concrete | Under development (MB Associates) |
| d. Mild steel (including gal-
vanized & enameled) | Available |
| 6. Back Covers | |
| a. Aluminum foils & polymer
laminates | Available |
| b. Tedlar, Mylar, Korad
(polymer films) | Available (DuPont, Excell, 3M) |
| c. Pigmented ethylene vinyl
acetate | Available (Springborn) |
| d. Others | Under development |
| 7. Gaskets | |
| a. EPDM (standard or custom
profiles) | Available (Pawling Rubber Co, others) |
| 8. Sealants | |
| a. "Tape" sealants | Available (Tremco, Pecora, 3M) |
| b. Gunnable sealants | Available (Tremco, 3M, others) |

In addition to materials, two encapsulation processes are being investigated:

- 1) Vacuum bag lamination
- 2) Liquid Casting

The suitability of these processes for automation is also being investigated, however, the selection of a process is almost exclusively dependent on the processing properties of the pottant. This interrelationship may have a significant influence on the eventual selection of pottant materials.

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide a maximum light transmission to the cell surface and optimize power output.

This report presents the results of the past quarter which has been directed at the continuing development and testing of pottants and other components.

The topics covered in this report are as follows:

- (1) the study of improved cure systems for the candidate lamination pottants, EVA and EMA. Curing agents are investigated that improve the quality of cure, improve the speed and lower the effective temperatures.
- (2) Evaluation of the soil resistant coatings after one year of outdoor exposure, and
- (3) a discussion of accelerated aging test techniques being implemented at Springborn Labs and presentation of the results of RS/4 exposure testing of candidate encapsulation materials.

III. Advanced Cure Systems

Chemistry

Two compounds, ethylene-vinyl acetate and ethylene-methyl acrylate, were chosen for the development of candidate pottant compounds for the lamination process. Their selection was based on their transparency, low processing temperatures and low cost. In order to function effectively in a module application, the property of creep resistance (lack of flow) at the module operating temperatures is a necessity. In order to accomplish this requirement, the copolymers must be compounded with chemical additives that permit the resin to flow during the lamination cycle but then subsequently crosslink (cure) at a later time. Crosslinking and/or vulcanization is defined as a process for converting a thermoplastic material or elastomer into a thermosetting material that will no longer flow upon the application of heat. This process converts the majority of the polymer molecules into a single network which then has the ability to retain many desirable physical and chemical properties of the base polymer under higher temperatures.

The two major chemical processes (not including radiation) that result in crosslinking are peroxide cure systems and sulfur cure systems. Only the peroxide cure systems have been considered for the two candidate elastomers. The main reason for this is that the sulfur cure systems, when used alone, will not cure these saturated compounds and in addition they result in the presence of dark sulfides that will reduce the optical transmission of the final compound. Peroxide cures, in addition, have many other desirable characteristics:

- Peroxide cures can be used with both saturated and unsaturated polymers,
- Peroxides produce vulcanizates with better heat aging properties, lower compression set, less color and lower odor,
- Peroxide vulcanizates generally have better low temperature flexibility than the sulfur cured compounds, and,

- Saturated elastomers that have been peroxide crosslinked have excellent aging and thermal stability characteristics. This is due to the lack of saturation in the polymer backbone and also to the higher bond energy of the carbon-carbon bond that results from peroxide crosslinking. The carbon-carbon bond energy is 82 Kcal/mole and is therefore as stable as most of the other bonds in the polymer. The sulfur cured elastomers have crosslinks composed of both carbon-sulfur and sulfur-sulfur bonds with energies of 66 Kcal/mole and 49 Kcal/mole, respectively. These are, therefore, weaker crosslinks and result in an inherently less stable compound.

The peroxide crosslinking of saturated polymers not only involves a large number of chemical reactions within the polymer itself, but also between peroxide decomposition residues, atmospheric oxygen (if present) and additives compounded into the rubber. The predominant reaction that gives rise to the formation of crosslinks is referred to as hydrogen abstraction. The basic steps of this chemical reaction are:

- (1) Peroxides thermally cleave to produce two oxy radicals. Acyl peroxides yield acyloxy radicals; $\text{ROOR} \xrightarrow{\Delta} 2\text{RO}\cdot$
alkyl peroxide yields alkoxy radicals.
- (2) Oxy radicals are very reactive and abstract hydrogen atoms from polymer chains, where P = polymer. $\text{PH} + \text{RO}\cdot \rightarrow \text{P}\cdot + \text{ROH}$
- (3) Two polymer radicals then combine to form a crosslink, resulting in cure. $2\text{P}\cdot \rightarrow \text{P} - \text{P}$

The ability of a radical, ($\text{R}\cdot$) to abstract hydrogen from a polymer, (P-H) to produce a new polymer radical, ($\text{P}\cdot$) is determined by the bond dissociation energies of R-H and P-H . In general, the more the bond dissociation energy of R-H exceeds that of P-H , the more rapid the hydrogen abstraction is likely to occur. The comparative ease with which hydrogens are abstracted by oxy radicals is a function of the hydrogen atom's reactivity. In order of descending reactivity, they are functionally; phenolic > benzylic > allylic > tertiary > secondary > primary. In polymers the degree of crosslinking varies depending on the type and number of hydrogens available for abstraction and the presence

of other reactive groups. The degree of crosslinking is affected by (a) the polymer type: saturated, unsaturated, chlorinated, etc.; (b) the peroxide type: dialkyl, diacyl, peroxyester, etc.; (c) the processing parameters: peroxide concentration, thermal decomposition rate, temperature, time, and (d) the interaction with other additives such as antioxidants, fillers, oils, stabilizers, etc.

Dialkyl peroxides are generally the most efficient and most widely commercially used for polymer crosslinking applications. Their high activation temperatures yields compounds of excellent thermal stability during compounding and reduced problems with "scorch" (premature curing). A wide variety of compounds are commercially available.

The factors guiding the selection of peroxide for the given application are as follows: (1) generation of crosslink: as the only modification of the polymer, (2) rapid decomposition at the desired cure temperature to yield efficient cure, but (3) survives the polymer compounding and processing steps, (4) effective in the presence of the other compounding ingredients such as antioxidants and UV stabilizers, (5) must be soluble in the polymer compound and preferably solid to prevent volatile losses, (6) is non-toxic before and after decomposition, and (7) does not sensitize the polymer to heat or ultraviolet light resulting in the accelerated aging of the cured elastomer. Peroxides containing aromatic groups (such as dicumyl peroxide) should be avoided due to their sensitizing effect on light stability.

Cure time and temperature can be determined in a peroxide cure system solely from knowledge of the rate of peroxide thermal decomposition. It is this reaction (homolytic cleavage and the generation of free radicals) that is the rate determining step in the curing or crosslinking sequence of reactions. The reaction follows first-order kinetics and is generally characterized by their half-life temperature. This term is more useful than "rate-constant" and is defined as the temperature at which fifty percent of the peroxide will decompose within a given time period. The half-life temperature is useful as an initial guide for the determination of processing safety and the selection of cure temperatures. The decomposition rate is independent of the amount of

peroxide present but does vary somewhat with the medium in which the decomposition is taking place. The thermal decomposition rates in polymer systems are usually slower (than in solutions) due to the reduced mobility of the resulting free radicals and the opportunity for recombination to occur.

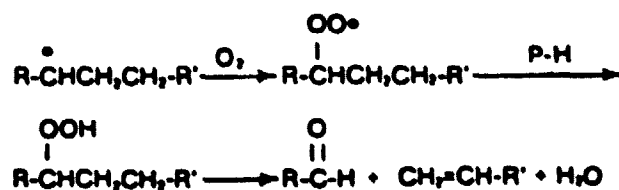
In commercial practice, polymer cure conditions are often selected to obtain six or seven half-lives in order to insure complete peroxide decomposition and the maximum development of physical properties. The following table illustrates the relationship between the half-life and the percent of peroxide decomposition:

<u>Number of Half-Lives</u>	<u>% of Original Peroxide Decomposed</u>
1	50.0
2	75.0
3	87.5
4	93.75
5	96.9
6	98.4
7	99.2
8	99.6

This general rule does not have to be followed providing that the following conditions are fulfilled: (a) the excess remaining peroxide is economically and chemically acceptable, (b) the ultimate in tensile strength and compression set is not required, and (c) the resulting gel content (degree of cross-linking) is acceptable for the intended application. It is found that the properties of modulus and tensile strength are within 90% of their ultimate values after the decomposition of approximately 80% of the peroxide. It is therefore recommended that the compound be cured for a minimum of three half-lives at the selected cure temperature.

A few cautions must be mentioned with respect to peroxide curing agents. These compounds decompose in the presence of strong oxidizing agents, reducing agents and accelerators (such as dimethyl aniline, cobalt naphthamate and metal salts). Acids in particular decompose the peroxide into ions. When this type of ionic decomposition occurs, alcohols and non-radical products result that cannot initiate the crosslinking reaction. Fillers and additives to the polymer should therefore be chosen that are not strongly acidic in nature.

Oxygen is also to be avoided during the cure stages of these compounds. Exposure to oxygen causes a competing reaction to occur that reduces the efficiency of the curing process, and more seriously, may lower the thermal stability of the final compound. In the presence of oxygen, the polymer radicals resulting from hydrogen abstraction may form hydroperoxides. The resulting hydroperoxides may then thermally decompose and result in polymer degradation according to the following mechanism:



Due to the fact that most cures are done either in closed molds or in vacuum bag laminators, as in the case of PV modules, the exclusion of oxygen is usually sufficient to prevent reactions such as these. Curing openly in the presence of air, however, must be avoided.

Ethylene/Vinyl Acetate

After an extensive investigation of transparent elastomers, ethylene/vinyl acetate (EVA) was selected from a class of low-cost polymers as being a likely candidate potting compound for use in the fabrication of solar cell arrays. Its selection was based on cost (approximately \$0.65 per pound) and an appropriate combination of high optical transparency and easy processing conditions. This polymer also showed the most promising properties for immediate use with a small amount of modification, but without extensive development efforts.^a

a. Willis, Baum, "Investigation of Test Methods, Material Properties and Processes for Solar Cell Encapsulants" DOE/JPL 954527-79/11, June 1979.

Fourteen commercial grades of EVA copolymers were surveyed from two manufacturers and a base resin, Elvax 150 (DuPont de Nemours Chemical Co.) selected on the basis of its high optical transmission and low melt viscosity. This resin formed the basis for the development of what is now a commercially available lamination grade solar cell pottant, Springborn Laboratories formulation number A9918. This compound has been widely evaluated and favorably received by the photovoltaic industry at large.

In addition to the many other technical activities, Springborn Laboratories is pursuing research concerned with the "technical optimization" of EVA, and other candidate encapsulation materials. Considerations include areas such as materials processing, lower temperature and faster cures, optimized thermal stability, optimized ultraviolet stability, adhesive reliability and lifetime prediction studies.

The first area to be reexamined in the formulation of potting compounds is that of cure parameters. Due to limitations imposed by the chemistry, the cure systems must be evaluated first and the other additives are subsequently selected for compatibility with the selection of curing agents. Experiments to evaluate new peroxide curing agents were conducted over the past quarter. The new compounds have only just become commercial and have the desirable properties of (a) aliphatic chemistry containing no UV sensitizing aromatic groups, (b) half life temperatures in the range of 90°C to 130°C (one hour half-life) for stable processing and rapid cure, (c) solubility and compatibility with ethylene copolymers and (d) the potential for faster and more efficient cure.

Four new peroxides were evaluated. All are products of Lucidol Division, Pennwalt Corporation; Buffalo, New York, and have the following properties:

	<u>Half-Life Temperature</u>		<u>Flash Point (Volatility)</u>	<u>% Active</u>
	<u>One Hour</u>	<u>Ten Hour</u>		
Lupersol 331-80B ^a .	111°C	93°C	40°C	75%
Lupersol 99 ^b .	118°C	99°C	77°C	75%
Lupersol TBEC ^c .	120°C	86°C	101°C	100%
*D-S606 ^d .	96°C	76°C	77°C	100%
	117°C	97°C		
Lupersol 101 ^e . (for comparison)	138°C	119°C	43°C	100%

*Contains two peroxy groups with differing half-lives

These compounds were blended into EVA copolymer (Elvax 150, DuPont) by cold milling at room temperature on a differential two roll rubber mill at a level of 1.5 weight percent. No other additives were incorporated. The resulting compounds were then cured by compression molding 20 mil thick plaques at a temperature of 150°C for twenty minutes. This basic test was useful for determining if the basic cure chemistry of the peroxide was compatible with the resin. The following table indicates the relative effectiveness of the peroxides as judged by gel content (percent insolubles) and the swell ratio (indication of the crosslink density):

<u>Peroxide</u>	<u>Cure in Elvax 150</u> [*]	
	<u>Swell Index</u> ^{**}	<u>Gel Content</u> ^{**}
Lupersol 331-80B	2,500	87%
Lupersol 99	2,800	89%
Lupersol TBEC	2,400	95%
D-S606	3,200	69%
Lupersol - 101	2,500	88%

*150°C/20 minutes

**In toluene

-
- a. 1,1-di(t-butylperoxy) cyclohexane
b. di-t-butyl diperoxyazelaate
c. O,O-t-butyl O-(2-ethylhexyl) monoperoxy carbonate
d. 4-(t-butylperoxycarbonyl)-3-hexyl-6-(7-(t-butylperoxycarbonyl) heptyl)cyclohexane
e. 2,5-dimethyl-2,5-di(t-butylperoxy) hexane

These initial results indicate that all the peroxides selected are successful in developing cure in the EVA base polymer, and subsequent experiments were conducted to determine chemical compatability in a fully formulated system and also to determine the time/temperature profiles for processing. A standard formulation was prepared with each, based on Springborn Laboratories' composition A9918, as follows:

	<u>Parts</u>
Elvax 150	100.0
Cyasorb UV-531	0.3
Tinuvin 770	0.1
Naugard - P	0.2
Candidate Peroxide	1.5

These compositions were then evaluated by determining gel content (degree of cure) as a function of time and temperature. The range of 110°C to 160°C was used to determine the speed efficiency of cure at the higher temperatures and to determine if problems would be encountered with premature cure at lower temperatures used in the sheet extrusion process (maximum temperature appx. 115°C). The following tables record the gel contents as a function of time and temperature:

Time/Temperature/Gel Profile

EVA Formulation with Lupersol 331-80B

(compound No. 14745-2)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2					79.5	84.5
5				88.8	86.9	88.7
10	0	68.2	84.2	89.3	88.0	87.6
15	0	80.4	87.4	92.4	88.9	
30	0	78.5	92.0	89.9		

Time/Temperature/Gel Profile
EVA Formulation with Lupersol D-S606
(compound No. 15267-A)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2					0	-
5				0	18.9	-
10	-	-	0	15.4	42.4	-
15	-	0	0	32.0	69.2	
30	-	0	0	40.0		

Time/Temperature/Gel Profile
EVA Formulation with Lupersol-99
(compound No. 14745-1)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2					low	75.2
5				low	70.7	79.0
10	0	low	low	72.2	77.7	79.9
15	0	8.1	69.5	74.9	78.4	
30	low	76.1	82.1	77.7	79.9	

Time/Temperature/Gel Profile
EVA Formulation with Lupersol TBEC
(compound No. 15259)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2			0	73.4	81.5	84.2
5			60.3	83.7	88.6	91.0
10	0	0	75.0	88.2	91.6	92.3
15	0	0	85.0	90.2	93.5	
30	0	65.0	82.7	92.2	92.6	

Time/Temperature/Gel Profile
Standard EVA A9918 Formulation, for Comparison (Lupersol 101)

<u>Time</u> <u>Minutes:</u>	<u>110°C</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2				1.0	4.1	29.5
5			0	11.8	21.1	73.0
10	0	0	1.0	23.5	63.2	82.6
15	0	0	2.3	59.3	88.3	
30	0	0	3.4	68.2		

With the exception of Lupersol D-S606, the results of advanced cure studies with completely formulated compounds appear very encouraging. The peroxides investigated all results in much higher cures of the EVA in shorter periods of time and at lower temperatures. Additionally, they should all be compatible with the extrusion process in which the temperature never exceeds approximately 115°C and the barrel residence time is in the order of only three minutes. Of the three, Lupersol 99 and Lupersol TBEC are a little more tolerant of premature crosslinking in the lower temperature ranges and both result in very rapid cures at higher temperatures.

The performance of the new peroxide curing agents may also be summarized as the times required for a specific gel content at known temperatures;

In EVA:	<u>Time Required for 70% Gel Content</u>				
	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
Lupersol 101	N/A	N/A	45	15	6
Lupersol 99	30	20	12	8	2
Lupersol 331-80B	15	10	5	2	2
Lupersol TBEC	30	10	4	2	1

These results indicate that, when compared to cure with Lupersol 101, the new peroxide, Lupersol TBEC, may be capable of resulting in equivalent cure in one third to one tenth the time, depending on the temperature selected. High degree of cure at a lower temperature is also desirable due to the energy saving, and reduced time required for heat transfer during lamination.

The rate of cure is dependent on the rate of peroxide decomposition and a close correlation has been found between the development of acceptable gel content (70%) in EVA and the half-life vs. temperature curve of peroxide decomposition. This graph is, therefore, useful for providing time and temperature data points required for cure. The half-life graphs for the peroxides of interest appear in the Appendix, Figure 1.

Of the four efficient peroxides presented, Lupersol TBEC currently appears to be the material of choice and should be considered as a replacement for the Lupersol-101 in future formulations. Its selection is based on; (a) it has the highest curing efficiency of the crosslinking agents examined to date, (b) it is 100% active and contains no DOP^a or mineral spirit dilutents based on its flash point, it has the lowest vapor pressure and consequently is less prone to volatile losses. Lupersol TBEC appears to be a highly efficient hydrogen abstractor in the ethylene/vinyl acetate base resin.

Ethylene/Methyl Acrylate

EMA has always been much more difficult to cure than EVA. Experiments were performed to see if the new peroxides presented an advantage in the fully compounded EMA pottant formulation. Compositions were prepared in the laboratory, as before and a standard EMA formulation (EMA 13439) was used as the base for this evaluation. The composition was:

Ethylene/Methyl Acrylate (Gulf Oil Chemicals, TD-938)	100.0
Cyasorb UV-531	0.3
Tinuvin 770	0.1
Naugard - P	0.2
Candidate Peroxide	1.5

The time/temperature gel profiles were determined as for the EVA, except over a slightly narrower temperature range. The following tables give the results for the new peroxides from 120°C to 150°C.

A. Dioctyl phthalate, used frequently as a peroxide diluent.

Time/Temperature/Gel Profile

EMA Formulation with Lupersol D-S606

(compound No. 15268-B)

<u>Time</u> <u>Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2				0
5			0	0
10	0	0	0	19.4
15	0	0	low	22.0
30	0	0	10.0	28.0

Time/Temperature/Gel Profile

EMA Formulation with Lupersol 331-80B

(compound No. 15257-B)

<u>Time</u> <u>Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2				7.3
5		0	0	52.6
10	-	43.8	49.8	56.7
15	-	70.1	53.0	55.7
30	-	70.0	59.9	59.6

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OF POOR QUALITY

Time/Temperature/Gel Profile
EMA Formulation with Lupersol-99
(compound No. 15257-B)


<u>Time</u> <u>Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2			0	0
5		0	0	53.4
10	0	v. low	36.8	57.8
15	0	v. low	61.6	51.7
30	v. low	57.3	51.1	51.6

Time/Temperature/Gel Profile
EMA Formulation with Lupersol TBEC
(compound No. 15257-C)

<u>Time</u> <u>Minutes:</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
2			0	69.3
5		0	53.2	68.8
10	0	26.3	51.6	74.0
15	0	40.7	54.2	71.3
20	low	46.3	59.6	71.3
30	15.0	52.8	63.2	72.4

Time/Temperature/Gel ProfileStandard EMA Formulation No. A-13439 (Lupersol 101)

(for comparison)

<u>Cure Time</u>	<u>120°C</u>	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>	<u>160°C</u>
2 minutes					9.5
5 minutes					21.5
10 minutes				0	48.6
20 minutes			0	37.0	48.6
30 minutes		0	low gel	53.0	
40 minutes		low gel	34.0	63.0	
60 minutes		low gel	47.0	65.0	

As may be seen the new peroxides are also of benefit in the EMA resin and result in much faster cure times and higher gel contents than the usual formulation employing Lupersol 101.

As was found with the EVA, Lupersol TBEC is overall the most efficient curing additive, however at lower cure temperatures (130°C) the Lupersol 331-80B gave the highest gel contents.

Comparing these new curing agents, the minimum times to a 50% gel level are given for each peroxide as a function of temperature.

Minimum Time to 50% Gel Content

	<u>130°C</u>	<u>140°C</u>	<u>150°C</u>
Lupersol 101	N/A	> 60	30
Lupersol 99	30	15	5
Lupersol 331-80B	12	10	5
Lupersol TBEC	25	5	< 2

It is apparent that the cure times in EMA may be reduced by a factor as much as fifteen and that gel contents as high as 73% may be obtained in the range of times and temperatures investigated. This is a considerable improvement over previous formulations.

Of the four efficient peroxides presented, Lupersol TBEC currently appears to be the material of choice for EMA also and should be considered as a replacement for the Lupersol-101 in future formulations. Its selection is based on: (a) it has the highest curing efficiency of the crosslinking agents examined to date; (b) it is 100% active, and (c) it has the lowest vapor pressure and consequently is less prone to volatile losses.

The EVA and EMA elastomers compounded with these agents can be processed like any other rubber and, in addition to lamination, are suitable for injection molding, compression molding, transfer molding and profile extrusion. The low softening point of these compounds allows processing at low temperatures, minimal tendency to scorch and the ability to be rapidly cured by an increase in temperature in the order of 30 to 40°C higher than the processing temperature.

The use of these new peroxides, especially Lupersol TBEC, presents obvious advantages to the PV industry. The lamination/encapsulation step may be operated at lower temperatures, higher speed, more efficient cure and wider cure latitudes. It is expected that a TBEC modified pottant would be much more tolerant of accidental or intended variations in the time/temperature cure schedule, thereby allowing a wider margin for equipment malfunction or process adjustment.

Before the development of a future commercially acceptable formulation based on Lupersol TBEC, other evaluations must be conducted to assess overall performance. Some of the concerns that remain are: (a) volatility - does the peroxide evaporate from the pottant during storage; (b) thermal stability - does the peroxide retain its activity in the pottant during storage at room temperature; (c) does the new cure system give rise to volatiles and bubbles during cure; (d) will the peroxide comfortably survive the extrusion process in plant trials, (e) are any chemical species developed that are incompatible with the other additives or result in photosensitization of the polymer?

In the near future, a pilot plant extrusion will be conducted with TBEC modified formulations of both EVA and EMA to assess the production scale performance of this compound as well as module fabrication, adhesion experiments, and accelerated aging experiments.

IV. Soiling Experiments

The performance of photovoltaic modules is adversely affected by surface soiling, and generally, the loss of performance increases with the quantity of soil retained on their surfaces. To minimize performance losses caused by soiling, photovoltaic modules not only should be deployed in low-soiling geographical areas, but also should have surfaces or surfacing materials with low affinity for soil retention, maximum susceptibility to natural removal by winds, rain, and snow; and should be readily cleanable by simple and inexpensive maintenance cleaning techniques.

The action of soiling is considered to include accumulation, natural removal by wind, rain, and snow; and activation of mechanisms that result in surface soiling that resists natural removal, thus requiring maintenance methods.

The theoretical aspects of soiling have been addressed recently in documents by the Jet Propulsion Laboratory.^{a.,b.} The basic findings of these studies show that the rate of soil accumulation in the same geographical area is material independent and that rainfall functions as a natural cleaning agent. The effectiveness of the cleaning effect of the rain is material dependent, however.

Based on the postulated mechanisms for soil retention on surfaces, certain characteristics of low-soiling surfaces may be assumed. These are: (a) hard, (b) smooth, (c) low in surface energy, (d) chemically clean of water soluble sales, and (e) chemically clean of sticky materials. It is possible that cost effective coatings having these required properties may exist and be applied to solar module surfaces and result in low maintenance costs and preserve the effective generation of power from these devices.

a. Cuddihy, E. F., "Encapsulation Materials Status to December 1979" LSA Project Task Report 5101-144, Jet Propulsion Laboratory, Pasadena, CA, January 15, 1980.

b. Hoffman, A. R., and Maag, C. R., "Airborne Particulate Soiling of Terrestrial Photovoltaic Modules and Cover Materials", Proceedings of the Institute of Environmental Sciences, May 11-14, 1980; Philadelphia, PA.

The candidate materials for the outer surface of solar modules currently consists of low-iron glass, Tedlar fluorocarbon film (DuPont) and a biaxially oriented acrylic film, Acrylar (3M Corporation; product X-22417). These materials are all relatively hard, smooth and free of water soluble residues, consequently experiments were conducted to determine if an improvement in soiling resistance could be obtained by the application of low surface energy treatments.

A survey of coating materials showed that very few commercial materials exist that could be useful for this purpose and that experimental compounds may also have to be synthesized.

A series of antimigration coatings designated FC-721 and FC-723 are available from 3M Corporation and are claimed to have extremely low surface energies in the order of 11-12 dynes/cm. These compounds are based on a flourinated acrylic polymer and are so effective in reducing surface tension that silicone oil beads up on the surface of glass treated with this material. The difficulty with these coatings is that they are very easily removed and have virtually no permanence on the surfaces attempted. They were, therefore, not used in the experimental soiling work and more durable candidates were selected.

A total of seven coatings/treatments were selected for soiling resistance evaluations, as follows:

1. L-1668, an experimental fluorochemical silane produced by 3M Corporation that is used to impart water and oil repellency to glass surfaces. This material is not yet commercial.
2. L-1668 following treatment of the surface with ozone activation (for the organic films only).
3. Dow Corning E-3820-103B, and experimental treatment consisting of perfluorodecanoic acid coupled to a silane (Z-6020). This compound is not commercially available.
4. The E-3820-103B following surface treatment with ozone to create active sites on the organic polymer films.

5. Glass resin 650, produced by Owens-Illinois (commercially available).
6. SHC-1000, a silicone based hardcoat resin produced by General Electric (commercially available).
7. WL-81 acrylic resin produced by Rohm and Haas (commercially available).

Ozone treatments are not used with the glass because no surface activation occurs in this case.

These coatings/treatments were applied to each of the three candidate outer surfaces using the recommended application technique. The organic film materials, Tedlar and Acrylar were supported by a piece of glass on the underside, and attached with a colorless and ultraviolet stable pressure sensitive adhesive. The completed test coupons were then mounted in outdoor racks on the roof of Springborn Laboratories' facilities in Enfield, Connecticut. Evaluation was performed monthly and a record of rainfall was kept in order to correlate soiling effects with precipitation.

The degree of soiling on the completed specimens was measured by power transmission using a specially designed standard cell device. This instrument measures the drop in short circuit current, I_{SC} , at negligible voltage drop (high input impedance) when the soiling specimen is placed between the standard cell and the light source. This method was found to be the measurement of optical transmission with a spectrometer. Poor correlation with I_{SC} and %T resulted from large experimental errors due to difficulties with mounting the soiling specimen to the port of the spectrometer.

The results of one year of outdoor exposure are recorded in Tables 1 through 4 in the Appendix. The soiling data is given in two forms; the change in short circuit current, I_{SC} , using a standard cell (Tables -A) and percent change in the short circuit current with respect to the unexposed control measurement (Tables -B). Examination of the -B Tables reveals the general trends in soiling which are also presented in graphical form, Figures 2, 3, and 4. Only the control and the three most effective treatments are graphed, for clarity.

Observation of the data reveals that a fluctuating but generally increasing loss in power is found for all specimens. The degree of loss varies according to the type of surface treatment and the particular month of exposure.

Sunadex glass, and the treatments applied to it, gave specimens with the best overall inherent soil resistance. The control and most of the coated specimens followed the same pattern of rising and falling simultaneously throughout the exposure period and the ninth month (winter) showed a dramatic decrease in power in all cases. A constant differential was found between the control measurements and the two most effective coatings, as may be seen, Figure 2. The two most effective coatings were L-1668 and the E-3820 fluorosilane treatments. Both showed significant improvements over the control specimens, and after 12 months gave power loss values of -1.0% and -1.3% respectively. The uncoated control specimen lost -3.1% of power throughput. All the other coatings/treatments gave inferior performance to the control. The specimens may be ranked according to the average % power loss over the twelve month period as follows:

<u>Coating/Treatment</u>	<u>Mean Power Loss</u>
L-1668	-1.18%
E-3820	-1.58%
Control	-2.59%
OI-650	-3.27%
SHC-1000	-4.16%
WL-81	-4.24%

The Acrylar acrylic film formulations soiled much more severely than the Sunadex glass specimens. All the specimens steadily lost power throughout the exposure period, however, almost all of the treatments had a beneficial effect. The uncoated control specimens soiled very badly and at one point (10th month) dropped to a low -10.8% power loss. After the twelfth month, the control value returned to a -7.8% power loss, with most of the treated specimens showing a 4 to 5% loss. The effectiveness of the coatings/treatments may be compared by ranking them according to the average power loss, as before. The results are as follows:

<u>Coating/Treatment</u>	<u>Mean Power Loss</u>
Ozone, E-3820	-3.07%
L-1668	-3.61%
E-3820	-3.69%
Ozone, L-1668	-4.03%
WL-81	-4.14%
OI-650	-4.39%
SHC-1000	-6.29%
Control	-6.35%

After the twelfth month, the treatment with the best final transmission resulted from the ozone treatment followed by E-3820. The results of the performance of the control and the three best coatings is displayed in Figure 3.

The third, and last, candidate outer surface to be investigated was Tedlar (100BG30UT), a transparent UV absorbing film of poly(vinyl fluoride) manufactured by DuPont. As with the Acrylar film, this material was mounted on glass squares with a pressure sensitive acrylic adhesive and deployed with the usual series of coatings/treatments. The overall performance of these specimens was better than the acrylar, but worse than the Sunadex glass. The control degraded steadily in power throughput reaching almost 9% loss in the tenth month and recovering to a total -6.5% loss by the twelfth month. All the coatings/treatments applied to the Tedlar were more efficient in retarding soil accumulation than the control. As with the previous two candidates, the fluorosilane treatments gave the best performance, the best being the E-3820 compound, which consistently gave a 4% to 5% improvement in performance over the exposure period and recovered to a loss of only 2.4% in the twelfth month measurement. Ranking the effectiveness of the coatings by mean power loss, as before:

<u>Coating/Treatment</u>	<u>Mean Power Loss</u>
E-3820	-1.70%
Ozone, L-1668	-3.17%
L-1668	-3.40%
Ozone, E-3820	-3.75%
WL-81	-4.00%
SHC-1000	-4.06%
Control	-5.06%
OI-650	-5.16%

The most severe soiling and consequent loss of power is seen in the eighth, ninth, and tenth months of exposure. These months were January, February, and March, during which period of time there was precipitation as snow, but virtually none as rain. All the specimens began to regain their transmission as the spring rains occurred in the eleventh and twelfth months (April and May). Increases were also seen earlier during the fourth month (September) in which there was also a large amount of rain (5.92"). Although even more rain occurred in the fifth month (October, 6.72") the specimens failed to regain much of their power transmission, and the overall values tend to decline after this point. (A Table of rainfall is included in the Appendix, Table 4.) This may be due, in part, to the loss of surface treatment in some cases. In Acrylar, treatment with L-1668 appears to outperform the specimen that is treated with ozone + L-1668 for the first five months, and then becomes gradually worse. This may be due to gradual loss of the L-1668 treatment that is prevented by the chemical activation with ozone in the latter case. Weathering effects that alter the surface chemistry are also likely. All the specimens retrieved from the outdoor aging racks were found to have lost a good deal of their water repellency. When sprayed with a jet of distilled water, all the exposed surfaces showed wetting, even the Sunadex/L-1668 specimen. In contrast, freshly treated surfaces are conspicuously water repellent and water droplets bead up instantly. An attempt was made to determine the surface energy of the exposed specimens by the contact angle technique, employing liquids of varying surface tension, however difficulties were encountered with the measurements and no meaningful data resulted.

In summary, low surface energy treatments based on fluorosilane chemistry appear to be effective in retarding the accumulation of dirt on the candidate outer surfaces of interest. The most effective soil retardant treatments identified to date are: for Sunadex glass, L-1668; for Acrylar, ozone activation followed by E-3820; and for Tedlar, treatment with E-3820.

After one year of outdoor exposure, the best treatments gave improvements of 2 1/2% to 4% in light throughput measured with a standard cell and light source. The removal of accumulated soil correlated well with rainfall but not with precipitation as snowfall.

The obvious visual difference in the wetting of exposed versus freshly prepared specimens indicates that the low surface tension treatments are prone to either chemical degradation or physical loss and may have to be replenished on a periodic basis. A maintenance schedule needs to be determined based on the cost of produced power gained by employing the coatings versus the cost of routine maintenance required for cleaning and recoating the surfaces. This study will be performed in the proceeding months of this program and the cost effectiveness of these approaches will be determined.

V. Accelerated Aging Experiments

The materials and designs selected for use in constructing solar cell modules must be capable of enduring the operating temperatures, insolation, precipitation and other elements of the outdoor exposure in the geographical region selected. Although the severity of these conditions may be fairly accurately gauged (climatic atlas, weather records, etc.) the performance of individual materials or combinations of materials is not as easily assessed. The chemical pathways and rates at which materials age in outdoor exposures are very complex and predictive techniques often turn out to be inaccurate.

Many degradation processes, including those that ultimately result in the failure of polymers are associated with thermal, chemical, mechanical, electrical, and radiation induced disruption of the chemical bonds. These stresses, either alone or in combination, can produce certain active chemical intermediates that may continue to react further with the polymer chain and result in macroscopic changes in the electrical, mechanical and optical properties of the material. In most polymers, the degradation mechanisms involve the stress-induced separation of electrons from the covalent bond that results in bond rupture and the formation of two free radical intermediates. These active free radicals may then propagate a series of reactions in which oxidation, discoloration, bond scission and loss of physical properties result.

The degradation of polymeric materials in outdoor weathering is caused primarily by sunlight, especially the ultraviolet component. In actuality, the deteriorating effect of light is usually enhanced by the presence of oxygen, moisture, heat, abrasion, etc. and in many cases may be referred to as photo-oxidation, resulting from the combined effects of oxygen and sunlight.

Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 290 nm before it reaches the surface of the earth. Thus, ultraviolet effects on plastic result primarily from wavelengths of approximately 290-400 nm, which constitute less than 4 percent of the total solar radiation reaching the earth.

The lower the wavelength of light, the greater is its potential to produce a chemical change in material. This energy must first be absorbed, however. Plastics vary considerably in their ultraviolet absorbing properties, but few are completely transparent in the 290 to 400 nm range. Once the radiant energy has been absorbed, the likelihood of chemical action will depend on the degree of absorption and the stability of the chemical bonds in the polymer. The induced chemical modifications are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation and transparency.

The degradative effects of these environmental stresses may be effectively inhibited by the incorporation of specially formulated additives to the polymer. Compounds that serve as ultraviolet light absorbers, antioxidants, hydroperoxide decomposers, metal deactivators, etc. may result in dramatic improvements in the service life of polymeric systems. Regardless of the inherent sensitivity of the polymer or the effectiveness of the additives and formulation, the question of lifetime under service conditions remains an important question.

Accelerated tests are frequently used to assess long term aging effects and compare the effectiveness of stabilizers in providing improved protection against environmental deterioration. Typically, properties such as tensile strength, elongation at break, apparent modulus, resistance to flex cracking and other properties are measured on samples aged for known periods of time under specified conditions. These tests are useful for determining the relative stability of polymers and formulations, but correlation with actual service is often poor. This is especially true for outdoor aging where the conditions of weathering cannot be precisely simulated or accelerated in the laboratory. Changes in the ratio of crosslinking to chain scission, temperature variations, differing oxygen concentrations, ultraviolet flux, dark cycle reactions, etc. add to the difficulty of correlation and performance prediction. Accelerated tests are useful, however, for the relative ranking and rating of materials and can provide approximate acceleration factors that are useable over a certain range.

In order to assess the relative stability of individual polymers and to determine the effectiveness of varying formulations, Springborn Laboratories is conducting a program of accelerated aging and life predictive strategies that should be useful for: (a) generating empirical and practical data relating to longevity, and (b) generating data that may be used in a scheme to predict properties as a function of exposure time and condition. If the resulting test data can be interpreted statistically, then plots of log property vs. temperature (Arrhenius) or log time vs. change in property (induction period) may provide quantitative information regarding formulation effectiveness and possibly life prediction analysis.

For the evaluation of individual materials and/or combinations of materials, seven types of exposure conditions are being used, as follows:

1. Outdoor aging: this is the simplest approach to accelerated aging when an exposure site is selected at which the environmental effects are the most severe and at which the polymer degrades most rapidly. To accomplish this, the selected sites, Arizona and Florida, have conditions of intense sunlight and sunlight plus high humidity. This method has been used extensively for the testing and rating of stabilized formulations and is valuable in that it simulates the actual use conditions of the candidate polymers. This approach has been widely used to establish regional acceleration factors and to provide reasonable estimates of the service life in specific localities.
2. Thermal Aging: this exposure involves the simple thermal aging of test specimens in a circulating air oven at varying times and temperatures. All the tests will be performed in sealed jars to prevent the abnormal loss of volatile stabilizers that is often encountered in forced air ovens and also to prevent cross-contamination of materials. Candidate encapsulation materials are being exposed at temperatures of 60°C , 80°C , 105°C and 130°C in atmospheres of both air and nitrogen. The first three of these temperatures are close to the worst case temperatures that may be expected for in modules mounted in open air (60°C), roof top mounted (80°C), and solar cell hot spotting (105°C). The highest temperature, 130°C , is being used to provide

an upper acceleration limit. Exposure in both air and nitrogen in the absence of light should also provide information concerning the inherent heat stability of compounds with and without oxidation reactions and without photo-induced reactions.

3. Outdoor Photothermal Aging racks (OPA): these are devices recently constructed at Springborn Laboratories that constitute a new approach to accelerated weathering. The predominant cause of outdoor deterioration is photothermal aging; the combination of heat and ultraviolet light. In all the laboratory techniques devised to date, it is mainly the light that is increased (photoacceleration) through the use of arcs and discharge lamps. In the OPA reactors, natural sunlight is used as the light source and the specimen temperature is increased. The OPA reactors consist of heated aluminum blocks surfaced with stainless steel and mounting hardware to hold the test specimens flush with the surface. The reactors are tilted at 45° South and the device turns on at sunrise and off at sunset. Three temperatures have initially been selected: 70°C, 90°C, 110°C. This approach eliminates the difficulties associated with the irregular spectrum of artificial light sources, exposes the specimens to other environmental conditions such as rain and pollution and additionally incorporates a dark cycle. The only acceleration therefore is in the temperature, all other environmental conditions being present in their natural occurrence and intensity.
 4. Controlled Environment Reactors (CER): this is a device designed and constructed at JPL^a and subsequently provided to Springborn Laboratories. It consists of a circular test chamber utilizing a filtered medium pressure mercury arc lamp, optional heaters and a water spray nozzle. The chamber permits the acceleration of solar ultraviolet up to 30 suns in intensity while maintaining a temperature of the absorbing surface at 30°C to 60°C. It is operated at a 60°C specimen temperature with twenty-two hours of "on" time and 2 hours of distilled water spray in the dark.
 5. RS/4 Sunlamp: this exposure condition consists of a rotating table carrying the test specimens beneath a General Electric RS type sunlamp. This lamp consists of a medium pressure mercury arc lamp in a quartz tube ballasted by a tungsten filament. The assembly is mounted in an inert gas
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- a. E. Laue, A. Gupta, "Reactor for Simulation and Acceleration of Solar Ultraviolet Damage" JPL Document 5101-135, September 21, 1979

filled bulb with a reflective coating and a transmission cut off near 290 nm. The bulb is additionally filtered with a piece of pyrex (cut off 300 nm) to insure the absence of spectra below the terrestrial limit. This condition is one of the most easily monitored and is widely used throughout the plastics industry for the purpose of comparative aging. This device is a modification of the test procedure ASTM D-1501, "Exposure of Plastics to Fluorescent Sunlamp" and is operated at a temperature of 50°C.

6. RS/4 Sunlamp - Wet: this condition is identical to the previous description but with the addition of a twenty minute spray of distilled water once every two hours. The water reservoir is thermostated to 50°C so that there is no fluctuation of temperature during the spray cycle.
7. RS/4 - 85°C/85% R.H.: this condition is identical to that described in (5.) except that the operating temperature has been raised to 85°C to increase the severity of the condition and to simulate the highest temperature suspected to result from the rooftop mounted solar module under the highest isolation. The relative humidity has also been increased to 85% to further initiate chemical reactions that may result from atmospheric moisture.

For a general program of materials evaluation, the failure of the polymer should be based on those properties that are relevant to the particular service application. With respect to candidate encapsulation materials, four life-limiting classes of properties were selected for evaluation: physical, optical, electrical and corrosion. These general properties were used for the preparation of a universal chart for polymer aging studies and serves as a universal chart for recording exposure dates, control properties, exposure hours and aging test results (see Tables 5 thru 16). These charts will be used to monitor the results of all the exposure conditions under consideration. Most of the test conditions have been set up and are in operation, however only the RS/4 (50°C-Dry) results have resulted in sufficient data to be reported in this document. The test periods vary, but are generally multiples of approximately 2,000 hours.

As a point of comparison, unstabilized polypropylene is physically degraded after approximately 160 hours and unstabilized low density polyethylene is degraded after approximately 450 hours of exposure. Outdoors, the degradation rates of these polymers varies according to their location. At Enfield, Connecticut, polypropylene with no stabilizers degrades to brittleness in approximately 8 months (5,700 hours) and low density polyethylene fails at about 18 months (12,000 hours). Areas where the sunlight is more intense, and there are fewer cloudy days, results in more rapid degradation. Exposure to higher temperatures is also significant; the degradation rate in polypropylene is almost doubled for every 10°C increase in temperature.

Due to the dependence variations in temperature and light exposure, the deterioration of plastics is also location dependent. Exposures in Mexico City have been found to be about twice the acceleration of the Enfield location.

Based on these actual outdoor lifetimes, approximate correlation factors can be calculated for RS/4 to outdoor weathering. In comparing RS/4 to Mexico City, for polypropylene the acceleration factor is approximately $\times 18$ and for polyethylene approximately $\times 13$. Although these acceleration factors provide a useful basis of comparison, it should be remembered that considerable variations may be found between different outdoor locations and/or simulated weathering conditions. Factors affecting the degradation rates include specimen thickness, spectral distribution, heat history, additives, temperature, polymerization catalyst impurities, etc. Due to the difference in degradation pathways, acceleration factors are also material dependent.

Another way in which an acceleration factor may be determined is by measuring the total energy in the ultraviolet range. Sunlight has approximately 4% of its total energy in the ultraviolet between the wavelengths of 295 nm and 400 nm. At air mass 1.5, with a total insolation of around $650 \text{ milliwatt/cm}^2$, the total ultraviolet energy received is in the order of 2.34 mw/cm^2 .^a Measurements of the RS/4 bulbs^b show that the integrated energy over the same wavelength range averages to 3.44 mw/cm^2 . This equals approx. 1.4 suns, however the

a. Brandhorst, "Terrestrial Photovoltaic Measurement Procedures" NASA TM 7370, 1977.

b. Estey, "Ultraviolet Spectra of Mercury Lamp" JPL-IOM #341-79-4712, September 4, 1979.

RS/4 lamp is on continuously whereas the sun, averaged over the year, is equivalent to only 5 hours of exposure per day. This, then, results in an overall acceleration factor of 6.7 for the RS/4 sunlamp, excluding the effect of increased temperature (50°C). Equivalently, one 1 year of outdoor exposure is accomplished in approximately 1,300 hours of RS/4. If one uses the general rule that reaction rates double for every 10°C increase in temperature, then an additional factor of 2 to 2.5 may be used to correct for temperature.

This results in an overall acceleration factor of between 14 and 17, which is in accordance with the experimental data from the aging of a number of plastics.

The test results and control properties of candidate encapsulation materials exposed to RS/4 sunlamp are given in Tables 5 thru 16, and reports the results of recently terminated exposures as well as materials still under exposure. The properties evaluated include tensile strength at break, ultimate elongation, tensile modulus (extrapolated to zero strain) and two measurements, gel content and swell ratio, that are sensitive to changes in the crosslink density. Changes in optical properties are monitored by visual appearance, the ultraviolet cut-off wavelength and total optical transmission. No values are given for the total integrated transmission at this time due to a change in the type of equipment to be used for these measurements. Due to the fact that solar cells have a response in the near infrared, and extended range spectrometer will be used for these measurements and will be reported at a later time. There is no intention to examine dielectric or corrosion properties in the RS/4 condition at this time, consequently these values are not given.

The candidate pottants are discussed first. By far, the longest specimen exposure accumulated to date is a small piece of an EVA formulation designated A8910C (Table 5). This compound is a prototype of the now commercial A9918 EVA formulation and was started in July, 1979. It has accumulated 30,000 hours of RS/4 exposure with little change in properties. The specimen is still clear, although a faint yellow color has appeared, and total integrated optical transmission in the range of 400 to 750 nm still gives a value of 89%. The surface

is free from any signs of fracture or tackiness and the specimen is still easily flexible. The test results show that tensile strength and elongation at break have decreased slightly and that the gel content has dropped from 72% to 45%. This change in properties is not considered to be deleterious to the function of this compound as a solar module pottant.

Following the obvious successful performance of this prototype EVA compound, a full set of specimens of the commercial A9918 formulation were placed under exposure (Table 6). The total accumulated exposure of this formulation reached 15,120 hours before an equipment malfunction (thermal override) degraded the remainder of specimens. At the end of the 15,120 hour exposure, the test results showed no change in the physical or optical properties and the compound appeared the same as the control specimens. These are excellent results for a transparent stabilized polyolefin. The base polymer, uncompounded Elvax 150 (DuPont), shows significant signs of degradation after only 500 hours of RS/4 and loses most of its tensile strength and surface hardness.

The second candidate lamination pottant is based on ethylene-methyl acrylate copolymer and was also exposed in its fully compounded and stabilized form as formulation number EMA 13439 (Table 7). This compound is continuing under exposure and to date has accumulated 7,600 hours. This material shows no significant change in tensile strength, however the modulus has decreased to 60% of control value, the ultimate elongation has increased by 20% and the swell ratio has doubled. These results indicate that there may be a decrease in the degree of cure (number of crosslinks) even though the gel content appears to be unaffected. These changes in properties are not considered to be deleterious to the use of this compound as a solar module pottant.

The candidate casting syrup pottants are also under RS/4 test evaluation, the first of which is an aliphatic urethane compound designated Z-2591 produced by Development Associates, Inc., N. Kingstown, Rhode Island (Table 8). This formulation contains a proprietary stabilizer system and prototypes of this formulation are claimed to have endured over six years of unprotected outdoor exposure with no loss of properties. Test specimens have so far endured 6,000 hours

of exposure with virtually no change in properties. The slight increase in tensile strength with time is probably due to residual curing reactions that slowly continue to postcure the compound. At the 6,000 hour mark the formation of a faint yellow color was noticed; however, the integrated transmission remains high at approximately 90%. This is excellent performance for a urethane compound, judging from previous testing of urethane compounds.

The second casting syrup pottant is an experimental poly(butyl acrylate) compound (BA 13870) developed jointly between Springborn Laboratories and JPL. The formulation contains a first-cut stabilizer system and crosslinking additives to generate the cure. Specimens of this formulation are continuing to be exposed and, to date, have accumulated 7,600 hours of time. The performance of these materials has also been very good and, except for uniformly lower tensile strength values, shows no significant signs of change. The specimens are still clear, colorless, flexible and have optical transmissions of approximately 89%.

In substrate designed modules in which no glass is used, outer cover materials are essential. Pottants, by nature, must be rubbery and low in surface hardness, consequently they have a strong tendency to accumulate soil. A transparent outer cover is necessary to provide a weatherable, cleanable, and hard surface for the top of the module. Four candidate outer cover materials have also been under RS/4 exposure for some time. The first is Tedlar 100BG30UT (DuPont) poly(vinyl fluoride) film of 1 mil thickness that also contains a UV screening agent and costs $5¢/\text{ft}^2/\text{mil}$. This film is aging well and has accumulated 15,200 hours of exposure to date (Table 10). Although there has been a decrease of 20% in its tensile strength, no other properties appear to be affected. The optical transmission is still found to be close to 90% (400-750 nm) and the slightly hazy (natural) film shows no other signs of change. The other Tedlar, type 4462 (Table 11) does not appear to be quite as stable. After 10,800 hours the elongation was found to be only 38% of the control value and the tensile strength had increased by 40%. This indicates that perhaps some crosslinking is occurring in the film.

Of the four outer covers being examined, the most cost effective of these candidates is Acrylar film (X-22417) from 3M Corporation, ($2.25¢/\text{ft}^2/\text{mil}$ of thickness) and is a biaxially oriented acrylic film intended for outdoor applications.

To date, this film has been exposed to 12,000 hours of RS/4 exposure with no major change in properties, except a decrease in strength at break (Table 12). A drop in tensile strength to 50% of control value was observed after the first 1,500 hours and was initially thought to be due to stress relaxation of the polymer at the exposure temperature (50°C). To verify this speculation, aged and unaged specimens were compared for molecular weight degradation by intrinsic viscosity measurements. The unaged Acrylar X-22417 had an intrinsic viscosity of 0.54 dl/gm or an approximate molecular weight of 116,000 (M_v). The aged specimens were found to have viscosity average molecular weights of 100,000 at 1,440 hours exposure and 94,800 after 12,000 hours exposure. Although there has been little change in the tensile strength since the drop in the first 1,000 hours, the results indicate a slow decrease in molecular weight subsequent to this time. Apart from this observation, no other change in properties could be noticed.

The last outer cover to be examined is Fluorex-A available from Rexham Corp., Matthews, North Carolina. This film is a polymer alloy of poly(methyl methacrylate) and poly(vinylidene fluoride) with a UV absorber also blended in. This material is very expensive, at a cost of approximately 18¢/ft²/mil of thickness and was initially selected as an alternative in the event that the other candidates did not perform well. The test specimens were extended as far as 8,640 hours exposure (Table 13) and appeared to perform well with the exception of the scattered points measured for ultimate elongation. Due to the superior performance of the Tedlar film and the high cost of this product, experiments with Fluorex-A will not be continued.

The last category of materials to be evaluated for RS/4 aging are the candidate back cover films. These films perform the function of providing a reflective back surface for superstrate designed modules that aid in heat dissipation and also additionally provide environmental protection to the back layer of pottant. Three candidates were selected; Scotchpar 20CP-white (3M Corp.), Tedlar 100BS30 WH (DuPont), and Korad 63000 (Xcel-Georgia Pacific Corp.), Tables 14, 15, and 16, respectively. All these candidates have endured 8,000 hours of exposure to date and show no major change in any property.

RS/4 has proven to be a useful tool for determination of the relative stabilities of polymeric materials and assessing the efficiency of stabilizing additives and other compounding approaches. The difficulty encountered in the current program is that the candidate encapsulation materials are so stable that extremely long times are required before failure points result that may be used for the comparison of materials and formulations.

The more rigorous conditions that will be imposed in some of the other accelerated tests, such as CER and RS/4-85°C, should overcome this problem and provide methods for materials stability evaluations in shorter time frames.

The specimens currently under test will continue until signs of degradation become apparent and new compounds will be added to each test condition as new candidates and formulations are identified.

APPENDIX

TABLE 1A
Soiling Experiments

Soil resistant coatings; change in short circuit current
with standard cell. Twelve months outdoor exposure.

Treatment	%I _{sc} Sunadex (Plain)													
	0	1	2	3	4	5	6	7	8	9	10	11	12	△
None	90.5	89.0	88.7	88.7	88.8	87.8	88.0	88.4	87.9	86.2	87.6	88.7	87.7	-3.1
L-1668	89.7	89.9	88.6	88.5	89.4	89.3	89.3	88.8	88.8	85.8	87.6	88.8	88.8	-1.0
Ozone, Then L-1668	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E-3820	90.0	89.9	89.9	88.0	88.8	88.6	88.9	87.9	88.2	86.5	87.6	89.4	88.8	-1.3
Ozone, Then E-3820	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OI-650 Glass Resin	91.0	90.5	89.6	89.3	89.3	88.0	88.7	87.3	87.5	85.3	85.8	87.6	87.1	-4.3
SHC-1000	91.9	89.6	89.4	89.3	88.3	88.3	87.8	87.4	87.1	86.0	87.8	88.0	87.4	-4.9
WL-81 Rohm & Haas	90.7	88.0	88.7	88.7	86.2	86.7	87.3	87.0	86.4	83.5	86.1	86.0	86.9	-4.2

Legend: 0 = control value before exposure; referenced to standard cell
 1-12 = number of months exposure; % of original short circuit current
 △ = % change in I_{sc}

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TABLE 1B
Soiling Experiments

Soil resistant coatings; percent change in short circuit current with standard cell. Twelve months outdoor exposure.

Treatment	% Variation in I _{sc} Sunadex Glass												
	0	1	2	3	4	5	6	7	8	9	10	11	12
None	0	-1.5	-2.0	-1.9	-1.7	-3.0	-2.8	-2.3	-2.9	-4.7	-3.2	-2.0	-3.1
L-1668	0	+0.2	-1.2	-1.3	-0.3	-0.4	-0.4	-1.0	-1.0	-4.3	-2.3	-1.0	-1.0
Ozone, Then L-1668	-	-	-	-	-	-	-	-	-	-	-	-	-
E-3820	0	-0.1	-0.1	-2.2	-1.2	-1.5	-1.2	-2.3	-2.0	-3.8	-2.7	-0.6	-1.3
Ozone, Then E-3820	-	-	-	-	-	-	-	-	-	-	-	-	-
OI-650 Glass Resin	0	-0.5	-1.5	-1.9	-1.7	-3.3	-2.5	-4.1	-3.8	-6.3	-5.7	-3.7	-4.3
SiC-1000	0	-2.3	-2.7	-2.8	-3.6	-3.9	-4.5	-4.9	-5.2	-6.4	-4.5	-4.2	-4.9
WL-81 Rohm & Haas	0	-2.7	-2.2	-2.2	-4.5	-4.4	-3.7	-4.1	-4.7	-7.9	-5.1	-5.2	-4.2

Legend: 0 = control value before exposure; referenced to standard cell
1-12 = number months exposure; % of original short circuit current

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TABLE 2A
Soiling Experiments

Soil resistant coatings; change in short circuit current
with standard cell. Twelve months outdoor exposure.

Treatment	$\% I_{sc}$ Acrylar X-22417 On Glass													
	0	1	2	3	4	5	6	7	8	9	10	11	12	Δ
None	84.0	80.9	80.7	80.3	80.3	79.3	79.5	78.6	77.7	75.4	74.9	77.4	77.4	-7.8
L-1668	80.3	79.5	80.0	78.8	77.9	77.5	77.5	76.3	77.2	76.2	75.0	75.8	76.3	-5.0
Ozone, Then L-1668	84.5	81.6	82.4	82.1	82.0	81.5	81.8	80.7	80.3	79.2	79.3	80.7	80.6	-4.6
E-3820	80.0	78.5	78.7	78.1	77.7	77.7	77.9	76.9	76.9	74.6	74.5	76.5	75.7	-5.4
Ozone, Then E-3820	84.1	83.3	82.4	82.2	82.3	82.0	81.5	80.7	81.4	79.9	80.0	81.4	80.7	-4.0
OI-650 Glass Resin	81.1	79.3	78.9	79.5	78.4	78.1	77.8	76.9	77.3	75.3	75.1	76.9	76.8	-5.3
SNC-1000	82.1	78.9	77.8	76.9	77.9	76.2	77.1	77.0	76.7	74.9	75.9	77.1	75.7	-7.8
WL-81 Rohm & Haas	83.6	81.0	80.7	82.7	81.0	81.0	80.1	79.7	79.6	77.9	78.3	79.8	78.9	-5.6

Legend: 0 = control value before exposure; referenced to standard cell
 1-12 = number months exposure; % of original short circuit current
 Δ = % change in I_{sc}

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TABLE 2B
Soiling Experiments

Soil resistant coatings; percent change in short circuit current with standard cell. Twelve months of outdoor exposure.

Treatment	% Variation in I_{sc} Acrylic X-22417 Acrylic Film												
	0	1	2	3	4	5	6	7	8	9	10	11	12
None	0	-3.1	-3.9	-4.4	-3.7	-5.1	-5.4	-6.4	-7.5	-10.2	-10.8	-7.9	-7.8
L-1668	0	-0.8	-0.4	-1.8	-2.1	-3.5	-3.5	-5.0	-3.9	-5.1	-6.6	-5.6	-5.0
Ozone, Then L-1668	0	-2.9	-2.5	-2.8	-2.5	-3.4	-3.2	-4.5	-5.0	-6.3	-6.1	-4.5	-4.6
E-3820	0	-1.5	-1.6	-2.4	-2.3	-2.8	-2.6	-3.9	-3.9	-6.7	-6.8	-4.4	-5.4
Ozone, Then E-3820	0	-0.8	-2.0	-2.3	-1.8	-2.5	-3.1	-4.0	-3.2	-5.0	-4.9	-3.2	-4.0
SHC-1000	0	-4.1	-5.2	-6.3	-4.2	-6.5	-6.1	-6.2	-6.6	-8.8	-7.6	-6.1	-7.8
WL-81 Rohm & Haas	0	-2.6	-3.5	-1.0	-2.6	-3.1	-4.2	-4.7	-4.8	-6.8	-6.3	-4.5	-5.6

Legend: 0 = control value before exposure; referenced to standard cell
1-12 = number months exposure; % of original short circuit current

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TABLE 3A

Soiling Experiments

Soil resistant coatings; change in short circuit current with standard cell. Twelve months outdoor exposure.

Treatment	% I _{sc} Tedlar 100BG30UT On Glass													
	0	1	2	3	4	5	6	7	8	9	10	11	12	Δ
None	87.7	85.3	84.8	86.8	84.2	83.6	83.2	83.2	82.2	81.0	80.0	81.8	82.0	-6.5
L-1668	88.4	86.9	87.1	86.0	86.6	85.6	85.8	85.1	85.1	83.1	83.7	84.9	84.7	-4.2
Ozone, Then L-1668	88.1	87.4	87.3	86.2	85.9	85.6	85.4	85.0	85.1	82.9	83.7	84.8	83.9	-4.8
E-3820	86.0	86.5	86.0	83.0	85.2	84.7	84.5	85.2	84.9	83.9	82.7	84.2	83.9	-2.4
Ozone, Then 3820	86.0	82.8	83.5	86.3	83.6	82.6	82.8	82.3	82.2	81.0	80.5	82.6	82.5	-4.1
OI-650 Glass Resin	89.0	86.3	86.4	85.3	85.5	85.0	84.7	82.6	84.9	80.9	83.2	83.3	83.7	-5.6
SHC-1000	89.0	86.5	86.9	86.3	86.4	85.7	86.2	85.2	85.0	82.0	84.8	85.0	84.9	-4.6
WL-81 Rohm & Haas	87.7	86.5	84.8	84.7	84.7	84.6	85.2	83.9	84.4	81.9	83.1	83.4	83.7	-4.6
RTV-615 Silicone	88.5	86.6	85.1	84.4	-	82.1	80.4	78.6	75.6	70.8	68.8	68.8	68.8	-22.3

Legend: 0 = control value before exposure; referenced to standard cell
 1-12 = number months exposure; % of original short circuit current
 Δ = % change in I_{sc}

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TABLE 3B

Soiling Experiments

Soil resistant coatings; percent change in short circuit current with standard cell. Twelve months of outdoor exposure.

Treatment	% Variation in I_{sc} Tedlar 100BG30UT Film												
	0	1	2	3	4	5	6	7	8	9	10	11	12
None	0	-2.4	-3.3	-1.0	-3.5	-4.7	-4.7	-5.1	-6.3	-7.7	-8.8	-6.7	-6.5
L-1668	0	-1.5	-1.5	-2.7	-1.8	-3.8	-2.9	-3.5	-3.7	-6.0	-5.3	-3.9	-4.2
Ozone, Then L-1668	0	-0.7	-0.9	-2.1	-2.2	-2.8	-3.1	-3.5	-3.4	-5.9	-5.0	-3.7	-4.8
E-3820	0	+0.5	0	-3.5	-0.8	-1.5	-1.7	-0.9	-1.3	-2.4	-3.8	-2.1	-2.4
Ozone, Then E-3820	0	-3.2	-2.9	+0.3	-2.4	-3.9	-3.7	-4.3	-4.4	-5.8	-6.4	-3.9	-4.1
OI-650 Glass Resin	0	-2.7	-2.9	-4.1	-3.5	-4.5	-4.8	-7.2	-4.6	-9.1	-6.5	-6.4	-5.6
SHC-1000	0	-2.5	-2.4	-3.0	-2.6	-3.7	-3.1	-4.3	-4.5	-7.9	-5.6	-4.5	-4.6
WL-81 Rohm & Haas	0	-1.2	-3.3	-3.4	-3.0	-4.9	-2.8	-4.3	-3.8	-6.6	-5.2	-4.9	-4.6

Legend: 0 = control value before exposure; referenced to standard cell
 1-12 = number months exposure; % of original short circuit current

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TABLE 4

Soiling Experiments

**Rainfall Throughout the Exposure Period
Inches of Rainfall at Springborn Laboratories, Enfield, Connecticut**

Year:	1981							1982					
Month:	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Rainfall, Inches:	4.3	4.75	2.82	5.92	6.72	3.13	1.5	*	*	2.23	4.45	3.4	10.3

*No rainfall during this time, below freezing

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Exposure Condition ; RS/4 DRYMaterial : EVANotebook No: A8901CAtmosphere : AirTemperature : 50 °C

Description : Prototype formulation of A9918

Candidate pottant

Specimen	Exposure, Hrs.	0 (control)	15,520	22,720	30,000	35,000	
	Date : (add 4Khrs	7/9/79	11/8/80	7/8/81	5/8/82	12/2/82	
	Unit No.:	4	4	4	1		
	No. of Specimens	1	1	1	1		
Physical	Tensile strength, psi	1,890	1,590	1,580	1,450		
	Ult. elongation, %	677 %	600%	605 %	480%		
	Modulus , psi	at 100%strn 360	450	833	a.		
	Swell Ratio		b.	b.	12.9		
	Gel content , %	72%	b.	b.	45 %		
	Appearance	Clear	ok	ok	ok		
Optical	Total optical , %T						
	UV cutoff , nm	362	b.	365	367		
	Color *	Clear	1	1	2		
Elect.	Dielect. Stgth., V/mil		a.	a.	a.		
	Leak current , ma		a.	a.	a.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. insufficient specimen available
b. not measured

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1 = no change

4 = strong color

7 = melted

2 = fair color

5 = degraded

8 = broken

3 = moderate color

6 = extreme degradation

9 = surface cracks

Exposure Condition : RS/4 DRYMaterial : EVA A9918Notebook No: A12504-3Atmosphere : AirTemperature : 50 °CDescription : Candidate pottant ; standard commercial grade EVA

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	8,640	15,120	
	Date :	7/15/80	11/12/80	3/13/81	7/13/81	4/13/82	
	Unit No.:	3	5	5	3	3	
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	1,890	1,930	1,340	1,460	1,520	
	Ult. elongation, %	510	631	550	590	570	
	Modulus, psi	890	780	820	850	875	
	Swell Ratio	32.2	a.	a.	a.	28.5	
	Gel content, %	74%	a.	a.	a.	69.8%	
	Appearance	Transparen film	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	355	355	356	357	357	
	Color *	Clear	1	1	1	1	
Elect.	Dielect. Stgth., V/mil		b.	b.	b.	b.	
	Leak current, ma		b.	b.	b.	b.	
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient material

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1 = no change 4 = strong color 7 = melted
2 = faint color 5 = degraded 8 = broken
3 = moderate color 6 = extreme degradation 9 = surface cracks

Project No. 6072.1

POLYMER AGING STUDIESPage:
A-10Exposure Condition : RS/4 DryMaterial : EMA 13439Notebook No: 13872-1Atmosphere : AirTemperature : 50 °C

Description : Candidate pottant

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	7,608	10,000	
	Date :	5/26/81	9/27/81	1/27/82	4/13/82	7/22/82	
	Unit No.:	4	4	4	1		
	No. of Specimens	10	5	5	3		
Physical	Tensile strength, psi	2,000	2,690	2,420	2,400		
	Ult. elongation, %	570%	623%	647%	680%		
	Modulus, psi	3,240	a.	a.	2,000		
	Swell Ratio	11.2	a.	24.3	28.4		
	Gel content, %	62%	a.	20%	59%		
	Appearance	Clear	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm	354	a.	a.	360		
	Color *	Clear	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. not measured
b. insufficient sample

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1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

Exposure Condition : RS/4 DRYMaterial : PU Z-2591Notebook No: 14600Atmosphere : AirTemperature : 50 °C

Description : Candidate pottant - casting system

Specimen	Exposure, Hrs.	0 (control)	2,160	4,125	6,000		
	Date :	10/26/81	1/20/82	4/13/82	6/30/82		
	Unit No. .	6	6	6	6		
	Remaining No. of Specimens	22	18	14	11		
Physical	Tensile strength, psi	160	196	131	199		
	Ult. elongation, %	115	143	105	143		
	Modulus , psi	254	263	241	222		
	Swell Ratio	2.7	a.	3.3	3.45		
	Gel content , %	93.2%	a.	91.7%	93%		
	Appearance	transparent sheet	1	1	2		
Optical	Total optical , %T						
	UV cutoff , nm	366	366	367	367		
	Color *	Clear	1	1	2		
Elect.	Dielct. Stgth., V/mil		b.	b.	b.		
	Leak current , ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. not measured
b. insufficient sample

ORIGINAL SAMPLE
OF POOR QUALITY

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

Exposure Condition : RS/4- DRYMaterial : BA 13870Notebook No: 13870Atmosphere : AirTemperature : 50 °C

Description : Candidate pottant - casting system

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	7,608	10,000	
	Date :	5/26/81	9/27/81	1/27/82	4/13/82	7/22/82	
	Unit No. :	4	4	4	1		
	No. of Specimens	10	5	5	4		
Physical	Tensile strength, psi	293	147	162	172		
	Ult. elongation, %	110	95	98	97		
	Modulus , psi	90	87	85	91		
	Swell Ratio	2.39	a.	2.01	1.88		
	Gel content , %	86.4%	a.	88.3%	89.4%		
	Appearance	Clear	1	1	1		
Optical	Total optical , %T						
	UV cutoff , nm	385	a.	386	384		
	Color *	Clear	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current , ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. not measured
b. insufficient sample

ORIGINAL SAMPLES
OF POOR QUALITY

1 = no change	4 = strong color	7 = melted
2 = faint color	5 = degraded	8 = broken
3 = moderate color	6 = extreme degradation	9 = surface cracks

Project No. 6072.1

POLYMER AGING STUDIES

Page :

A-13

Exposure Condition : RS/4 DRYMaterial : Tedlar 100BG30UT Notebook No: A12811Atmosphere : AirTemperature : 50 °C

Description : Outer cover candidate

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	9,744	15,120	20,000
	Date :	9/20/80	12/20/80	4/20/81	10/3/81	5/20/82	12/9/82
	Unit No. :	6	6	3	3	3	
	(Starting No.) No. of Specimens	10	20	13	8	5	
Physical	Tensile strength, psi	17,700	16,819	16,200	16,400	14,500	
	Ult. elongation, %	71%	70	78	69	65	
	Modulus , psi	2.4×10^5	6×10^5	2.5×10^5	10×10^5	2×10^5	
	Swell Ratio	na	na	na	na	n/a	
	Gel content , %	na	na	na	na	n/a	
	Appearance	hazy	1	1	1	1	
Optical	Total optical , %T						
	UV cutoff , nm	356	355	356	354	354	
	Color *	slight blue hazy	1	1	1	1	
Elect.	Dielct. Stgth., V/mil		a.	a.	a.	a.	
	Leak current , ma		a.	a.	a.	a.	
Corrosion *	Copper dust, %T	-	na	na	na	na	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. insufficient sample

ORIGINAL RECORD
OF POLYMER QUALITY

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

Exposure Condition : RS/4 DRYMaterial : Tedlar 4462Notebook No: 13406-3 OF POOR QUALITYAtmosphere : AirTemperature : 50 °C

ORIGINAL PAGE IS

Description : Candidate outer cover

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	8,640	10,800	16,000
	Date :	1/26/81	5/26/81	9/27/81	1/27/82	4/20/82	11/22/82
	Unit No.:	#7	#7.	#7	#7	#7	
	No. of Specimens	10	5	5	5	3	
Physical	Tensile strength, psi	10,600	14,900	15,200	17,000	15,000	
	Ult. elongation, %	180	53	71	75	70	
	Modulus , psi	2×10^5	a.	a.	a.	2.1×10^5	
	Swell Ratio	Insoluble	n/a	n/a	n/a	n/a	
	Gel content , %	Insoluble	n/a	n/a	n/a	n/a	
	Appearance	hazy blue film	1	1	1	1	
Optical	Total optical , %T						
	UV cutoff , nm	365	a.	365	365	365	
	Color *	v. lite blue slt. haze	1	1	1	1	
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	
	Leak current , ma		b.	b.	b.	b.	
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient sample

1 = no change

2 = faint color

3 = moderate color

4 = strong color

5 = degraded

6 = extreme degradation

7 = melted

8 = broken

9 = surface cracks

Exposure Condition : RS/4 DRYMaterial : Acrylar X22417Notebook No: A12528Atmosphere : AirTemperature : 50 °CORIGINAL PAGE IS
OF POOR QUALITY

Description : Outer cover candidate ; biaxially oriented acrylic film

Specimen	Exposure, Hrs.	0 (control)	1,440	2,880	5,760	12,000	
	Date :						
	Unit No.:	4	4	4	4	4	
	No. of Specimens	10	5	5	5	5	
Physical	Tensile strength, psi	24,000	24,000	13,200	15,000	14,500	
	Ult. elongation, %	1	1	1	6	7	
	Modulus, psi	4.4×10^5	4×10^5	a.	6×10^5	5×10^5	
	Swell Ratio	Soluble	n/a	n/a	n/a	n/a	
	Gel content, %	Soluble	n/a	n/a	n/a	n/a	
	Appearance	Transparent film	1	1	1	1	
Optical	Total optical, %T						
	UV cutoff, nm	382	381	382	382	381	
	Color *	Clear	1	1	1	1	
Elect.	Dielect. Stgth., V/mil		b.	b.	b.	b.	
	Leak current, ma		b.	b.	b.	b.	
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					
Notes :		\overline{M}_v^c	116,000	100,000	a.	a.	94,800

a. not measured

c. Viscosity average molecular weight

b. insufficient specimen

1 = no change

4 = strong color

7 = melted

2 = faint color

5 = degraded

8 = broken

3 = moderate color

6 = extreme degradation

9 = surface cracks

Exposure Condition : RS/4 DRYMaterial : Fluorex-ANotebook No: 13406-2Atmosphere : AirTemperature : 50 °C

Description : Outer cover candidate ; Acrylic/vinylidene fluoride alloy

Specimen	Exposure, Hrs.	0 (control)	2,880	5,760	8,640		
	Date :						
	Unit No.:	7	7	7	7		
	No. of Specimens	10	5	5	3		
Physical	Tensile strength, psi	5,560	3,790	5,800	5,440		
	Ult. elongation, %	328	44	47	113		
	Modulus, psi	1.4×10^5	a.	a.	a.		
	Swell Ratio	Soluble	n/a	n/a	n/a		
	Gel content, %	Soluble	n/a	n/a	n/a		
	Appearance	Transparent film	1	1	1		
Optical	Total optical, %T						
	UV cutoff, nm	340	a.	340	341		
	Color *	Clear	1	1	1		
Elect.	Dielect. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes :

a. not measured

b. insufficient specimen

ORIGINAL PAGE IS
OF POOR QUALITY

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Project No. 6072.1

POLYMER AGING STUDIES

Page:

A-17

Exposure Condition : RS/4 DRYMaterial : Scotchpar 20CPNotebook No: 14321-2Atmosphere : AirTemperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	4,320	6,648	8,000		
	Date :	7/13/81	1/13/82	4/20/82	6/15/82		
	Unit No.:	8	8	5	5		
	Remaining No. of Specimens	10	12	8	6		
Physical	Tensile strength, psi	29,400	28,000	28,000	25,600		
	Ult. elongation, %	27	15	20	15		
	Modulus, psi	3.6×10^5	a.	a.	5×10^5		
	Swell Ratio	Soluble	n/a	n/a	n/a		
	Gel content, %	Soluble	n/a	n/a	n/a		
	Appearance	White film	1	1	1		
Optical	Total optical, %T	Opaque	n/a	n/a	n/a		
	UV cutoff, nm	n/a	n/a	n/a	n/a		
	Color *	White	1	1	1		
Elect.	Dielct. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient sample

ORIGINAL PAGE IS
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9 = surface cracks

Project No. 6072.1

POLYMER AGING STUDIES

Page :

A-18

Exposure Condition : RS/4 DRYMaterial : Tedlar 100BS30WH Notebook No: 14321-3Atmosphere : AirTemperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	4,320	6,648	8,000		
	Date :	7/13/81	1/13/82	4/20/82	6/15/82		
	Unit No.:	8	8	5	5		
	Remaining No. of Specimens	10	12	8	6		
Physical	Tensile strength, psi	14,000	14,500	14,600	14,300		
	Ult. elongation, %	59	68	62	65		
	Modulus, psi	2.8×10^5	a.	2.3×10^5	2.7×10^5		
	Swell Ratio	N/A	n/a	n/a	n/a		
	Gel content, %	N/A	n/a	n/a	n/a		
	Appearance	White film	1	1	1		
Optical	Total optical, %T	Opaque	n/a	n/a	n/a		
	UV cutoff, nm	N/A	n/a	n/a	n/a		
	Color *	White	1	1	1		
Elect.	Dielct. Stgth., V/mil		b.	b.	b.		
	Leak current, ma		b.	b.	b.		
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a		
	Copper metal	—					
	Aluminum	—					
	60/40 Solder	—					
	Nickel	—					
	Titanium	—					
	Silver	—					

Notes : a. not measured
b. insufficient sample

ORIGINAL FILED IN
OF POOR QUALITY

1 = no change
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4 = strong color
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6 = extreme degradation

7 = melted
8 = broken
9 = surface cracks

Project No. 6072.1

POLYMER AGING STUDIES

Page:

A-19

Exposure Condition : RS/4 DRYMaterial : Korad 63000Notebook No: 14321-1Atmosphere : AirTemperature : 50 °C

Description : Back cover candidate

Specimen	Exposure, Hrs.	0 (control)	1, 440	4, 320	6, 648	8, 000	
	Date :	7/13/81	9/13/81	1/13/82	4/20/82	6/15/82	
	Unit No.:	8	8	8	5	5	
	Remaining No. of Specimens	10	12	8	4	3	
Physical	Tensile strength, psi	4, 250	5, 120	4, 690	3, 995	5, 040	
	Ult. elongation, %	28	18	16	19	15	
	Modulus , psi	2×10^5	a.	a.	1.3×10^5	1.5×10^5	
	Swell Ratio	Soluble	n/a	n/a	n/a	n/a	
	Gel content , %	Soluble	n/a	n/a	n/a	n/a	
	Appearance	White film	1	1	1	1	
Optical	Total optical , %T	Opaque	n/a	n/a	n/a	n/a	
	UV cutoff , nm	n/a	n/a	n/a	n/a	n/a	
	Color *	White	1	1	1	1	
Elect.	Dielct. Stgth., V/mil		b.	b.	b.	b.	
	Leak current , ma		b.	b.	b.	b.	
Corrosion *	Copper dust, %T	n/a	n/a	n/a	n/a	n/a	
	Copper metal	---					
	Aluminum	---					
	60/40 Solder	---					
	Nickel	---					
	Titanium	---					
	Silver	---					

Notes : a. not measured
b. insufficient sample

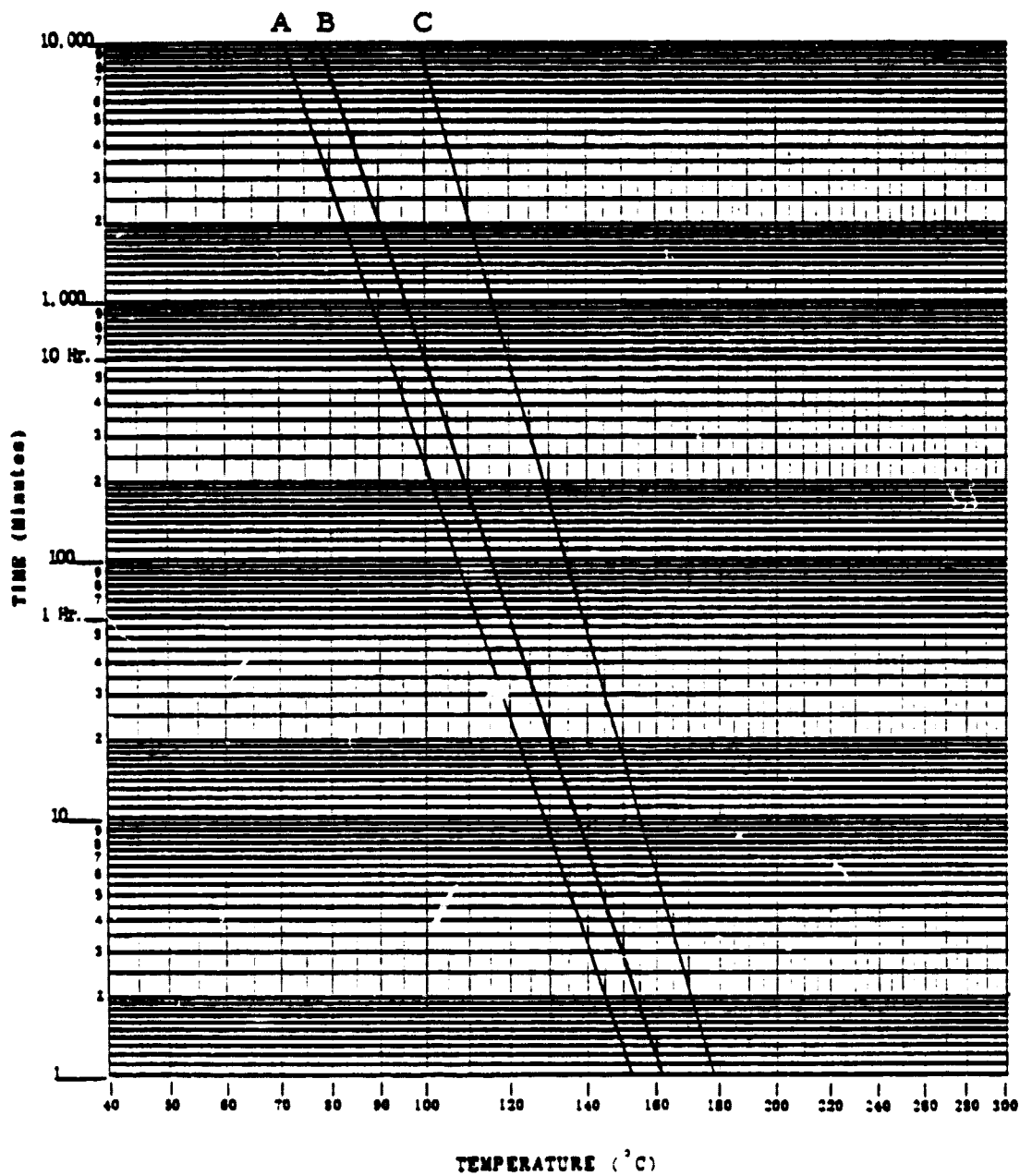
ORIGINAL PAGE IS
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Half-Life / Temperature Graph
New Peroxides^a.



- A. Lupersol 331-80B
B. Lupersol TBEC, Lupersol-99
C. Lupersol 101

a. Decomposition of 0.2 molar solutions in dodecane

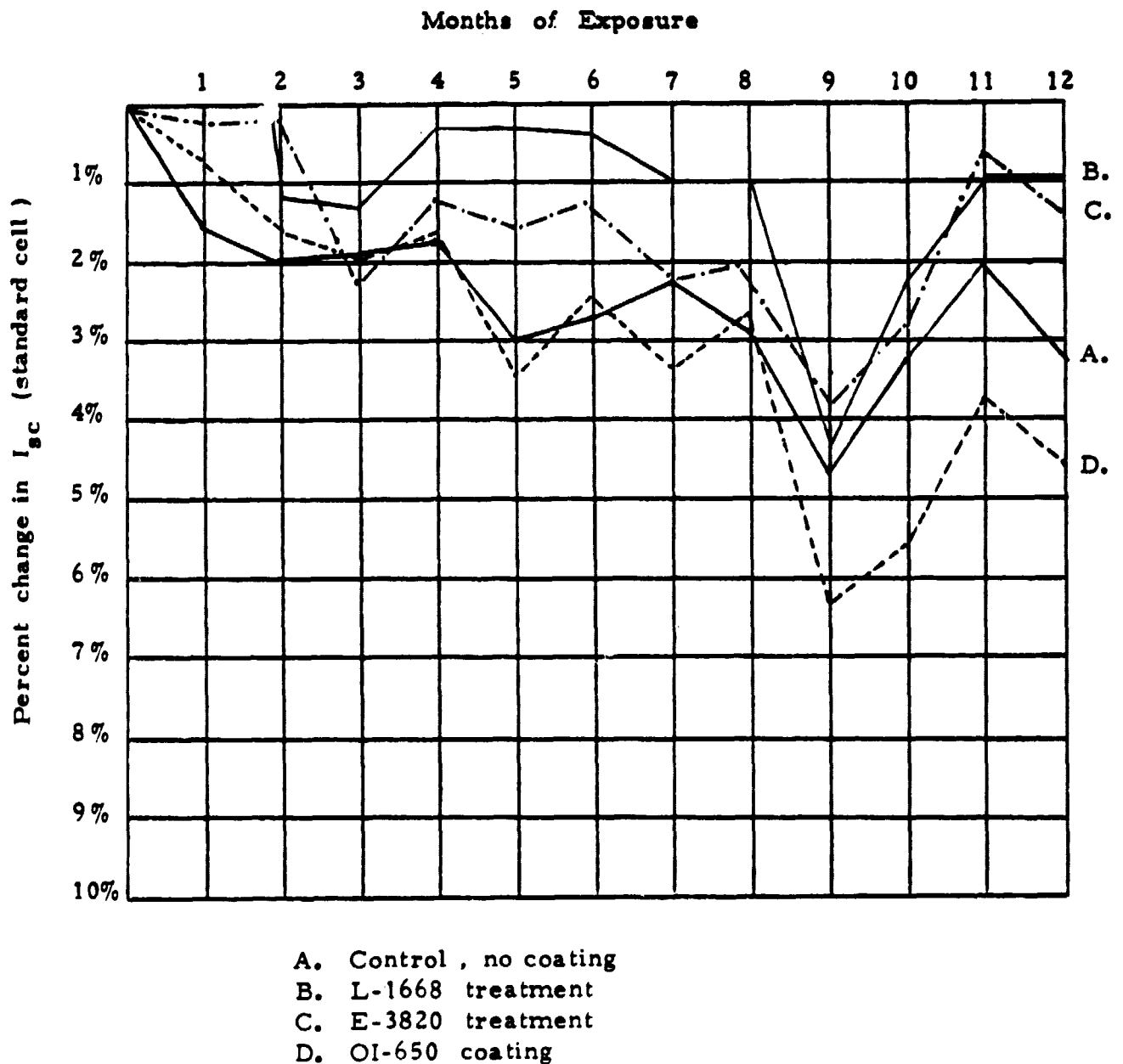
Figure 2.

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Soiling Experiments

Percent change in short-circuit current
after twelve months outdoor exposure .

Sunadex Glass



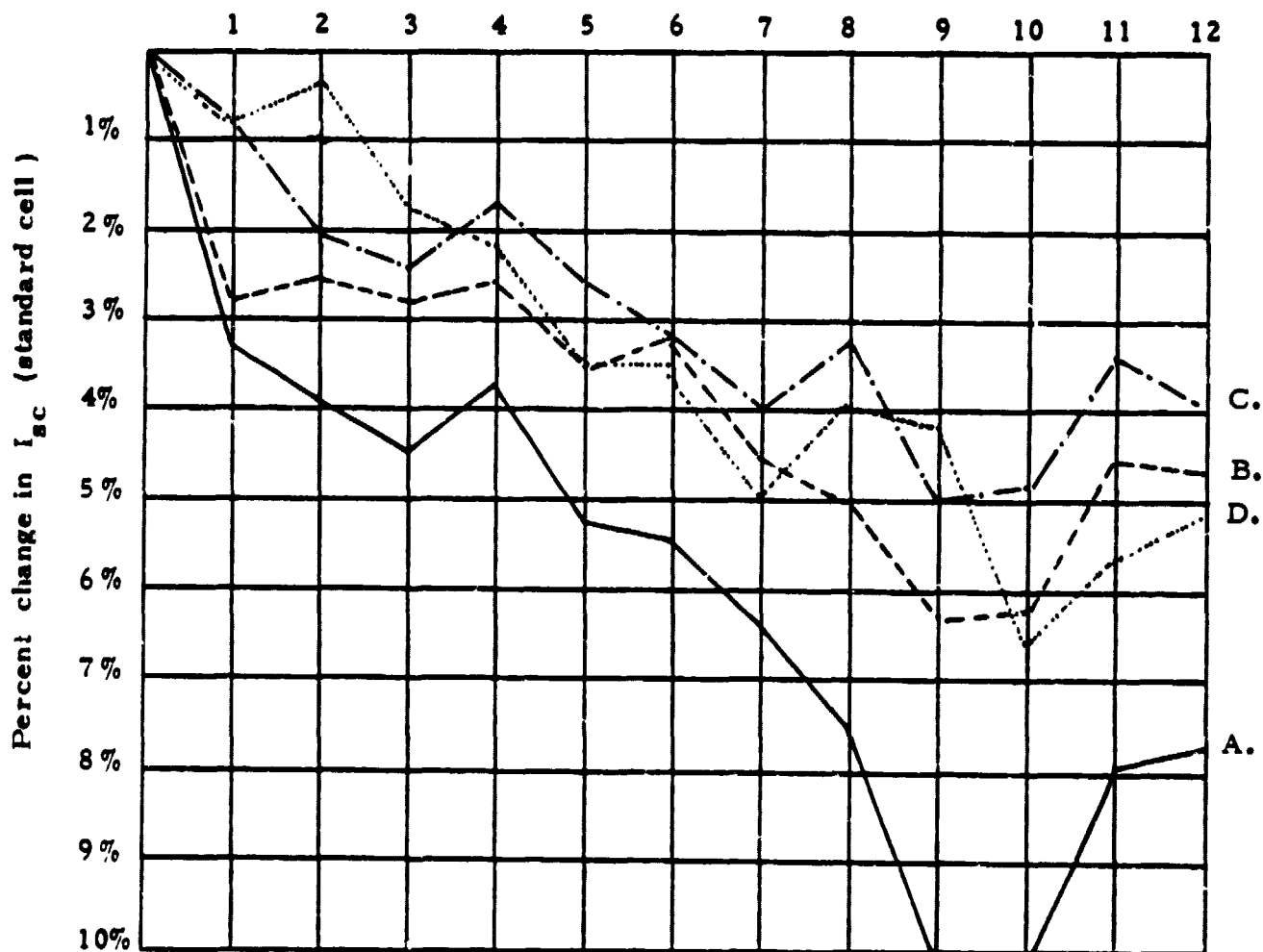
Soiling Experiments

Percent change in short-circuit current
after twelve months of outdoor exposure .

Acrylar Film

(X-22417 , 3M Corp.)

Months of Exposure



- A. Control , no coating
- B. Ozone followed by L-1668
- C. Ozone followed by E-3820
- D. L-1668 treatment

Figure 4.

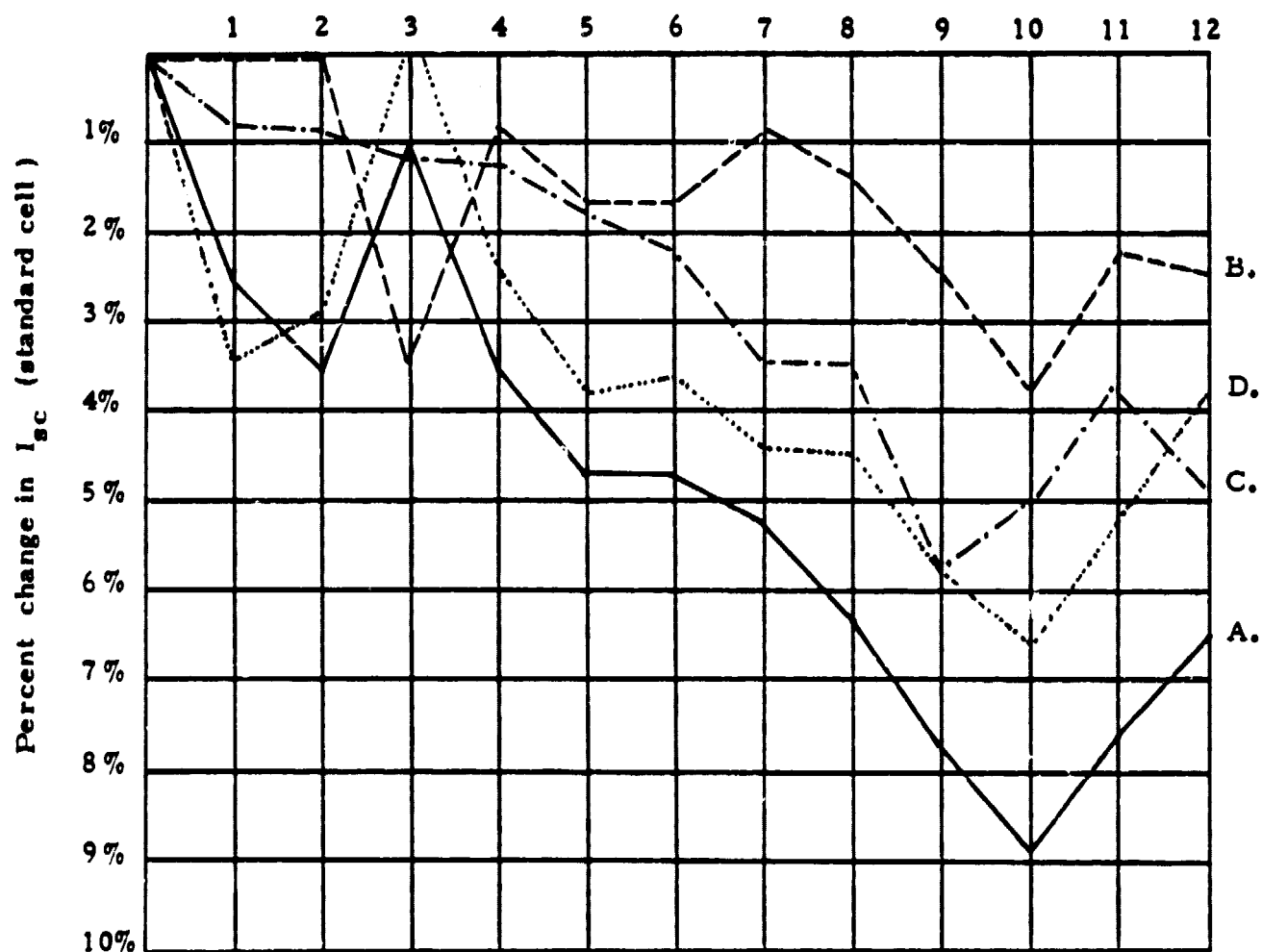
ORIGINAL PAGE IS
OF POOR QUALITY.Soiling Experiments

Percent change in short-circuit current
after twelve months of outdoor exposure.

Tedlar Film

(100BG30UT , DuPont)

Months of Exposure



- A. Control , no coating
 B. E-3820 treatment
 C. Ozone followed by L-1668
 D. Ozone followed by E-3820